



ELECTROLYTIC CAPACITOR

08 035224

Field Of The Invention

5 The present invention concerns improved ~~elec~~
B ~~trelytic~~ capacitors and particularly ~~electrolytic~~
capacitors employing a pseudocapacitor-type cathode
and a wet slug-type capacitor anode to achieve im-
proved performance including increased energy stor-
10 age density.

Background Of The Invention

15 Tantalum wet slug capacitors have long been
known in the capacitor arts. An example of the
structure of a wet slug tantalum capacitor is de-
scribed in U. S. Patent 4,780,797. Fundamentally,
as described there, the wet slug capacitor includes
a tantalum or tantalum-plated container that is the
20 cathode or negative terminal of the electrolytic
capacitor. An electrolyte and a porous sintered
tantalum anode are disposed within the container.
Tantalum forms a native oxide on exposed surfaces
that may be increased in thickness by anodic oxida-
25 tion. In the conventional wet slug capacitor, both
the anode and cathode have insulating tantalum oxide
coatings that are spaced apart from each other but
are both in contact with the electrolyte, typically
a sulfuric acid solution. Since sulfuric acid is
30 electrically conductive, a conductor-insulator-con-
ductor structure including metal, oxide coating, and
electrolyte is present at both the anode and the
cathode. Each of these conductor-insulator-conduc-
tor structures is itself a capacitor, i.e., an anode
35 capacitor and a cathode capacitor. The capacitances

of these electrode capacitors are to some degree determined by the thickness of the oxide layers formed on the anode and the cathode. Increasing the thickness of the anode oxide layer but not the cathode oxide layer, for example, by anodic oxidation, increases the breakdown voltage that a wet slug capacitor can withstand but reduces the overall capacitance of the capacitor. Typical breakdown voltages for a single capacitor can range from ten to one hundred twenty-five volts.

In the wet slug capacitor, the anode capacitance is effectively electrically connected in series with the cathode capacitance. As is well known, the net capacitance of two capacitors connected in series is smaller than the smaller of the capacitances of the two capacitors. Because the oxide layer at the anode of a wet slug capacitor is usually much thicker than the thickness of the oxide layer at the cathode, the anode capacitance of a wet slug capacitor is smaller than the cathode capacitance. For example, in a typical structure, the anode capacitance may be 3,100 microfarads and the cathode capacitance may be 8,700 microfarads. The resulting net capacitance of that capacitor is about 2,300 microfarads.

Although wet slug capacitors having useful capacitances and breakdown voltages can be readily produced, there is always a desire to increase the capacitance per unit volume of those capacitors, i.e., the energy storage density, without a reduction in the breakdown voltage. One proposed method of increasing the energy storage density of a wet slug capacitor is described in the cited patent. In that patent, a number of metallic films are deposited on the inside of the container of the capacitor.

In particular, it is suggested that a film selected from the platinum group of metals, i.e., ruthenium, rhodium, palladium, and platinum, be alloyed with the tantalum of the container in segregated islands where the native oxide has been removed from the tantalum. Various techniques can be employed to deposit the platinum group metal, such as sputtering and electrolytic or electroless plating, followed by a heat treatment at a relatively high temperature, for example, from 925°C to 1,500°C. Preferably, a platinum group metal layer is subsequently deposited on the islands to form a spongy layer. The platinum group metals apparently improve the energy storage density of capacitors having the structure described in the patent.

In U. S. Patent 4,942,500, a platinum group metal is applied to a capacitor cathode by cladding, i.e., by rolling a very thin layer of the platinum group metal with the tantalum metal. Explosive bonding is also mentioned. In U. S. Patent 5,043,847, electrolytic co-deposition of a base metal and platinum group metal on the inside surface of a wet slug capacitor container is described. Addition of the platinum group metal by these techniques is said to increase the energy storage density.

A different type of electrolytic capacitor, frequently referred to as an electrochemical capacitor, employs so-called pseudocapacitive electrodes. These capacitors generally have metal oxide electrodes including a substrate of titanium or tantalum. Typically, a hydrated chloride of the metal, which may be ruthenium, is dissolved in isopropyl alcohol and sprayed on a heated titanium or tantalum substrate. The heat drives off the solvent, resulting in the deposition of a metal chloride. That

chloride is heated to a high temperature in air to convert the metal chloride to an oxide. For example, the metal chloride film may be heated to about 250°C for approximately one-half hour to completely
5 remove the solvent and to drive off water. Thereafter, in a second elevated temperature step, for example, at approximately 300°C, a high surface area film of the oxide of the metal, for example, ruthenium oxide, is formed on the substrate. The oxide
10 film is highly porous, meaning that it has a very high surface area. An electrochemical capacitor includes such an electrode as the anode and as the cathode, typically with a sulfuric acid solution electrolyte. The electrical charge storage mechanism is not yet fully understood. Electrical charges
15 may be stored on the very large surface areas of the two electrodes, providing the capacitance characteristic. Electrical charges may be stored by a reversible change in the oxidation state of a material in an electrode. No matter what the charge
20 storage mechanism is, it is substantially different from the charge storage mechanism of a wet slug capacitor electrode.

Although electrochemical capacitors can provide
25 much higher energy storage densities than wet slug capacitors, the breakdown voltage of individual cell electrochemical capacitors is very low, typically only about one volt, i.e., essentially the dielectric breakdown voltage of the electrolyte. Even if
30 electrochemical capacitors are connected in series, it is difficult to produce a practical capacitor with a breakdown voltage comparable to the breakdown voltages of wet slug capacitors. Thus, electrochemical capacitors have not found wide usage.

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Summary Of The Invention

It is an object of the invention to provide an improved electrolytic capacitor having a practical
5 breakdown voltage and a high energy storage density.

According to one aspect of the invention, an electrolytic capacitor comprises a metal container having an inside surface and an outside surface and functioning as a cathode of the capacitor, a porous
10 coating including an oxide of a metal selected from the group consisting of ruthenium, iridium, nickel, rhodium, platinum, palladium, and osmium disposed at the inside surface of the container in electrical communication with the container, an anode selected
15 from the group consisting of tantalum, aluminum, niobium, zirconium, and titanium disposed within the container and spaced from the porous coating, and an electrolyte within the container in contact with the porous coating and the anode.

20 According to another aspect of the invention, ~~an electrolytic capacitor~~ comprises a first metal body having opposed first and second surfaces and functioning as a cathode of the capacitor, a porous coating including an oxide of a metal selected from
25 the group consisting of ruthenium, iridium, nickel, rhodium, platinum, palladium, and osmium disposed on the first surface of the first metal body, an anode electrode selected from the group consisting of tantalum, aluminum, niobium, zirconium, and titanium
30 disposed on a second metal body opposite and spaced from the first metal body as the anode of the capacitor, an electrolyte in contact with the porous coating and the anode, and a sealant disposed between and contacting the first and second metal bod-
35 ies, sealing the electrolyte between the first and

second metal bodies.

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According to yet another aspect of the invention, ^a~~an electrolytic~~ capacitor includes a plurality of electrolytic capacitor cells, each cell including
5 a first metal body having opposed first and second surfaces, a porous coating including an oxide of a metal selected from the group consisting of ruthenium, iridium, nickel, rhodium, platinum, palladium, and osmium disposed on the first surface of the
10 first metal body, an anode electrode selected from the group consisting of tantalum, aluminum, niobium, zirconium, and titanium disposed on the second surface of the first metal body, a spacer disposed between the porous coating and the anode for preventing
15 direct contact between the porous coating and the anode wherein the ~~electrolytic~~-capacitor cells are disposed in a serial arrangement with the porous coating of one first metal body disposed opposite the anode of the next adjacent first metal body in
20 the serial arrangement with the spacer disposed between, separating, and preventing direct contact between the opposed porous coatings and the anodes in the serial arrangement, a second metal body having first and second opposed sides disposed at one
25 end of the serial arrangement and including a porous coating including an oxide of a metal selected from the group consisting of ruthenium, iridium, nickel, rhodium, platinum, palladium, and osmium disposed on one side of the second metal body and opposite an
30 anode of a first metal body in the serial arrangement, but no anode, and functioning as the cathode of the ~~electrolytic~~-capacitor, a third metal body having opposed first and second sides disposed at another end of the serial arrangement and including
35 ing an anode selected from the group consisting of

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5 tantalum, aluminum, niobium, zirconium, and titanium
disposed on one side of the third metal body and
opposite a porous coating of a first metal body in
the serial arrangement, but no porous coating, and
functioning as the anode of the ~~electrolytic~~ capaci-
tor, an electrolyte disposed between and contacting
the respective opposed porous coatings and anodes in
the serial arrangement, and a sealant disposed be-
tween and contacting adjacent metal bodies in the
10 serial arrangement, sealing the electrolyte within
the capacitor and between adjacent metal bodies.

15 In the invention, one electrode of an electro-
lytic capacitor is an ~~electrolytic~~ wet slug capaci-
tor-type electrode, for example, the anode. The
other electrode is an electrochemical-type capacitor
electrode employing a porous coating including an
oxide of a metal selected from the group consisting
of ruthenium, iridium, nickel, rhodium, platinum,
palladium, and osmium. For the same capacitance
20 value, the cathode of a capacitor according to the
invention is reduced in size compared to a conven-
tional wet slug capacitor electrode. If the volume
of the conventional wet slug capacitor for a partic-
ular capacitance is maintained, then the anode of a
25 capacitor according to the invention can be in-
creased in size relative to the conventional wet
slug capacitor anode, increasing the capacitance and
the energy storage density as compared to a conven-
tional wet slug capacitor. In addition, if the ca-
30 pacitance of a conventional wet slug capacitor is
maintained, then the volume of a corresponding ca-
pacitor according to the invention can be made
smaller than the conventional wet slug capacitor,
increasing energy storage density. A high breakdown
35 voltage, characteristic of the conventional wet slug

capacitor, is obtained in the invention because of the presence of the conventional wet slug capacitor anode while realizing increased energy storage density because of the presence of the pseudocapacitor cathode.

Brief Description Of The Drawings

Figure 1 is an exploded view of a capacitor according to an embodiment of the invention;

Figure 2 is a cross-sectional view of an alternative embodiment of a capacitor according to the invention;

Figure 3 is a cross-sectional view of a single cell prismatic capacitor according to an embodiment the invention; and

Figure 4 is a cross-sectional view of a multiple cell prismatic electrolytic capacitor according to an embodiment of the invention.

Description Of Preferred Embodiments

Figure 1 is an exploded view of an embodiment of the invention and Figure 2 is a cross-sectional view of a related but different embodiment of the invention. Like reference numerals are used in those and all other figures to designate the same elements.

In Figure 1, an electrolytic capacitor according to the invention includes a metal container 1, typically a tantalum container. However, metals other than tantalum may be used in embodiments of the invention. Typically, the container 1 is the cathode of the electrolytic capacitor and includes a lead 2 that is welded to the container. An end

seal, a cap 3, includes a second lead 4 that is electrically insulated from the remainder of the cap by a feedthrough 5 seen in Figure 2. In the assembled capacitor, the cap 3 is bonded to the container 1 by conventional means, for example, by welding. The insulating feedthrough 5 of the lead 4 is likewise conventional and may include a glass-to-metal seal through which the lead 4 passes. A conventional porous sintered tantalum anode 6 is electrically connected to the lead 4 and disposed within the container 1. Direct contact between the container 1 and the anode 6 is prevented by electrically insulating spacers 7 and 8 within the container 1 that receive the ends of the anode 6. The retaining insulators 7 and 8 are conventional.

In the embodiment of the invention shown in Figure 1, a metal body 11, such as a metal foil, is disposed within and is in electrical communication with the metal container 1. The communication may be established, for example, by welding the metal body to the inside surface of the metal container 1. The inside surface of the metal body 11 includes a porous coating 12 including a metal oxide. The porous coating preferably includes an oxide of a first metal. The first metal is selected from the transition metals in Group VIII of the Periodic Table of Elements that have at least two stable oxidation states in the electrolyte used in the capacitor. The metal is particularly selected from the group consisting of ruthenium, iridium, nickel, rhodium, platinum, palladium, and osmium. The porous coating may also include an oxide of a second metal selected from the group consisting of tantalum, titanium, and zirconium. The second metal oxide is not believed to be electrically active but

increases the surface area of the porous coating and/or extends the mixture used to form the porous coating. The second metal oxide component is not essential in the capacitor cathode. In a preferred
5 embodiment of the invention, the porous coating includes oxides of ruthenium and tantalum.

In the embodiment of the invention shown in Figure 2, a porous coating 13, i.e., the same as the porous coating 12 of the embodiment of Figure 1, is
10 formed directly on the surface of the metal container 1. The metal body 11 employed in the embodiment of the invention shown in Figure 1 is thus eliminated, reducing costs.

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15 In the ~~electrolytic~~ capacitors of Figures 1 and 2, each capacitor includes two electrodes. One of the electrodes, the anode 6, is preferably a conventional sintered porous tantalum anode used in conventional wet slug tantalum capacitors. In
20 addition, the anode may be made of another one of the so-called valve metals, i.e. aluminum, niobium, zirconium, and titanium. The other electrode includes the metal container 1, the metal body 11 with the porous coating 12 or the porous coating 13 on the container 1 and is similar to one of the elec-
25 trodes used in a pseudocapacitor. As a result of that combination, advantages of a pseudocapacitor and of a wet slug capacitor are achieved without the disadvantages of either of those known capacitor structures. The cathode capacitance is greatly in-
30 creased over the cathode capacitance of a conventional wet slug capacitor because of the very large surface area and the very small effective "plate separation". (Plate separation refers to modeling of the cathode as a theoretical parallel plate ca-
35 pacitor with two plates having areas A separated

from each other by a distance d .) Because of the increased capacitance contributed by the pseudocapacitor cathode for a particular volume, the cathode can be reduced in size, providing space for an anode of increased size, larger than the wet slug capacitor anode of a conventional wet slug capacitor having the same capacitance. Alternatively, for the same volume as a conventional wet slug capacitor, a much larger capacitance can be achieved.

As already described with respect to one example of a conventional wet slug capacitor, a sintered tantalum anode has a capacitance of 3,100 microfarads. A pseudocapacitor cathode replacing the cathode of the conventional tantalum electrolytic capacitor (having a capacitance of 8,700 microfarads) has a capacitance of 0.2 farads. Since, as in the conventional apparatus, these electrode capacitances are electrically connected in series, in the capacitor according to the invention, the overall capacitance is calculated as 3,050 microfarads, an increase in capacitance of one-third over the conventional wet slug capacitor. Measured capacitances of capacitors in accordance with the invention confirm the accuracy of this calculation.

When a voltage is applied to a capacitor according to the invention, the voltage is divided across the oxide film on the anode and the pseudocapacitor cathode. Because the capacitance of the anode is much smaller than the capacitance of the pseudocapacitor cathode, the voltage applied to the capacitor naturally divides unequally across the electrodes. A large proportion of the applied voltage appears across the anode oxide film and not across the electrolyte. A much smaller proportion of the applied voltage appears across the pseudo-

capacitor electrode. As a result, a capacitor according to the invention can sustain a much higher voltage, i.e., has a much higher breakdown voltage, than a conventional pseudocapacitor. In other
5 words, increased capacitance as observed in a pseudocapacitor is achieved in the invention without the disadvantage of the low breakdown voltage observed in those known capacitors. As well known in the art, the oxide film on the anode, made of a valve
10 metal, and particularly tantalum or aluminum, can be increased to a desired thickness, increasing the capacitor breakdown voltage, in an electrolytic, anodic oxidation process.

The porous coating, whether formed on a metal
15 body or directly on the inside surface of a metal container of a capacitor according to the invention, is formed using conventional processes. Examples of methods of forming such porous coatings on metal bodies are described in numerous publications. For
20 example, the formation of similar capacitor electrodes is described in U. S. Patent 4,766,522. Electrolysis cell electrodes including similar but very thick coatings are described in some of the examples appearing in U. S. Patent 3,632,498.

25 In a preferred process, hydrated ruthenium chloride ($\text{RuCl}_3 \cdot 3\text{H}_2\text{O}$) is dissolved in isopropyl alcohol to form a solution having a concentration of one to three percent. Preferably, an enhancing agent, such as a chloride of tantalum, is added to the so-
30 lution. A mixture having an atomic ratio of about one ruthenium atom to three tantalum atoms produces a higher capacitance film than do mixtures with different ratios of tantalum to ruthenium atoms. The rate of dissolution of the chlorides in alcohol can
35 be increased by the addition of about 10 milliliters

of hydrochloric acid per 100 milliliters of isopropyl alcohol. Titanium, nickel, and zirconium compounds may also be used in place of the tantalum chloride to improve performance of the capacitors according to the invention. While the preferred process employs chlorides because of their solubility, other inorganic and organic salts of the metals can also be employed in the formation of the porous coating.

Whether the substrate on which the porous coating is disposed is a metal body or the inside surface of a metal capacitor container, the substrate is preferably roughened before deposition of the coating to increase the adhesion of the solution subsequently applied to the substrate in forming the coating. The surface may be roughened by chemical treatment, for example, with sulfuric acid, hydrochloric acid, or oxalic acid, or by a mechanical process, such as sand blasting, although mechanical processes are not preferred over chemical treatments. If a native oxide is present on the surface, the method described in U. S. Patent 5,098,485 may be employed to ensure a good electrical contact between the substrate and the porous coating. The tantalum or titanium substrate is then heated to about 85°C and the solution is applied by spraying. The elevated temperature of the substrate results in rapid evaporation of the alcohol solvent, leaving the formerly dissolved chlorides in place as a film on the substrate. As an alternative to spraying, the substrate may be dipped in the solution. However, spraying a heated substrate results in prompt drying that permits the deposition of relatively thick films quickly by repeated spraying of the substrate.

After the formation of the metallic chloride film, the substrate is heated to a temperature of about 250°C in air to drive off any remaining solvent and the water contained in the hydrated chloride. In addition, some of the chlorine may be driven off at that time. The heating continues in air for about one hour after which the temperature is increased to approximately 300°C for a time sufficient to oxidize the metal components of the coating. For example, the oxidizing treatment in air may continue for about two hours. The resulting coating is insoluble in water and sulfuric acid, has pores as small as 50 Angstroms, and has a surface area of up to about 120 square meters per gram.

The completed capacitor includes an electrolyte 14, shown in Figure 2, disposed between and in contact with both of the electrodes to provide a current path between the electrodes 6 and 11 or 6 and 13. The electrolyte may be any of the conventional electrolytes employed in electrolytic capacitors, most typically a sulfuric acid solution when the anode is tantalum. In other constructions, different electrolytes are used. For example, when the anode is aluminum, an ammonium salt dissolved in glycol or a glycol-like solvent may be employed because sulfuric acid attacks aluminum. When the cathode is nickel, then potassium hydroxide is preferred over sulfuric acid as an electrolyte. As is conventional, the materials of construction of the capacitor that are contacted by the electrolyte are chosen to be impervious or extremely resistant to the effects of the particular electrolyte employed.

The embodiments of the capacitor according to the invention shown in Figures 1 and 2 are similar in shape and arrangement to conventional tantalum

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wet slug capacitors. Other embodiments of the invention resemble the "jelly roll" structure of conventional foil capacitors. In that configuration, the anode slug is replaced by a conventional foil of
5 tantalum or aluminum, or any of the other valve metals, wound in jelly roll fashion as the anode. Some decrease in capacitance is experienced in replacement of the anode slug with the rolled foil. However, an increased capacitance over the conventional
10 jelly roll foil capacitors is achieved in the invention because of the presence of the cathode including the porous coating.

Capacitor cells of still different geometrical configuration according to embodiments of the invention can be easily made. The capacitors cells can
15 be interconnected in series to form a capacitor having a higher breakdown voltage than an individual cell. An example of an embodiment of the invention including a single cell is shown in Figure 3. A
20 capacitor according to an embodiment of the invention and including a plurality of cells arranged and interconnected serially is shown in Figure 4.

B In Figure 3, ~~an electrolytic~~ capacitor according to an embodiment of the invention includes opposed metal bodies 21 and 22, preferably thin metal
25 plates or foils. The plates are separated by an insulating sealant 23 that is adhered to both of the plates 21 and 22. Figure 3 (and Figure 4) is a sectional view and the capacitor can have any desired
30 shape in plan. For example, if the capacitor has a circular shape in plan view, then preferably the sealant 23 is a unitary, annular body adhered to both plates, sealing and forming a sealed package. If the capacitor has other shapes in plan view, it
35 is still preferred that the sealant 23 be a unitary

body following the perimeter of the plates, i.e.,
the capacitor, defining a closed volume between the
two plates 21 and 22. The sealant may extend beyond
the plates. The sealant may be a laminate of resin
5 layers that are thermally sealed to each other.

The plates 21 and 22 are preferably tantalum,
although other metals, such as titanium, may be em-
ployed. A porous tantalum anode 24 or an anode of
another valve metal is formed on plate 21 and dis-
10 posed within the sealed volume defined by the plates
21 and 22 and the sealant 23. The inside surface of
the plate 22 is coated with a porous coating includ-
ing a metal oxide prepared as described above,
thereby forming a pseudocapacitor cathode. In order
15 to avoid direct contact between the anode 24 and the
porous coating on the inside surface of the plate
22, a spacer is interposed between the anode 24 and
the plate 22. Most preferably, the spacer includes
a plurality of masses of an electrically insulating
20 material disposed between and contacting the anode
24 and the plate 22. An electrolyte, such as a so-
lution of sulfuric acid, potassium hydroxide, or an
ammonium salt, is present between and in contact
with the anode 24 and the plate 22. The electrolyte
25 directly contacts the spacer 25 so that the spacer
material must be impervious to the electrolyte.

In the capacitor of Figure 3, the plate or met-
al body 22 has a porous coating including a metal
oxide formed on one surface in the same manner that
30 the porous coating is formed on metal body 11 or on
the inside surface of the container 1 of the embodi-
ments of the invention already described. After the
formation of that porous coating, the spacer 25 is
deposited on the porous coating. The individual
35 spacing masses may be formed by printing, such as

silk screening, while dissolved in a solvent that is subsequently removed, for example, by the application of heat, or by the deposition of individual masses of a melted electrically insulating material.

5 If the electrolyte is sulfuric acid, then the spacer may be made of polyolefin, polyethylene, or polypropylene, for example. Other kinds of spacers can be employed instead of the individual masses illustrated in Figure 3. For example, a glass fiber paper,

10 plastic fibers, or an ion-permeable material, such as NAFION, may be inserted between the anode 24 and the plate 22 to prevent direct contact of the electrodes. The spacing masses may be located on the anode 24 rather than on the porous coating or may

15 not be fixed to either electrode.

The plate 21, which is preferably the same size and shape as the plate 22, is masked over the area where the sealant 23 will be adhered. Plate 21 may be a thin metal foil, for example, 1 mil in thickness.

20 Tantalum powder held together by a binder, such as stearic acid, if needed, is applied to the plate 21 under pressure. The tantalum powder binder is driven off, for example, by heat, and the powder is sintered in an inert atmosphere to produce a high

25 surface area porous anode. Finally, that anode is anodically oxidized to form tantalum oxide over the surface of the sintered powder to a desired thickness. Similar anodes may be made of aluminum, niobium, zirconium, and titanium.

30 The plates 21 and 22 are then brought together with the spacer 25 preventing direct contact of the plate 22 and the anode 24. The spacer masses may be about 1 mil high, 5 mils in diameter, and spaced about 50 mils apart in a regular pattern. In order

35 to form a stable assembly, the sealant 23 is then

applied at the periphery of the two plates 21 and 22 to form a closed package for retaining the electrolyte. A hot melt polyolefin may be employed as the sealant 23. Subsequently, the sealant can be broken or opened so that the electrolyte 26 can be injected into the package. The interior of the package may be evacuated in advance of injecting the electrolyte. After the electrolyte is in place, the sealant is resealed with additional sealant material. Leads can be easily attached to the plates 21 and 22 before, during, or after assembly of the capacitor.

A capacitor according to an embodiment of the invention and including a plurality of individual capacitor cells 30 interconnected in series is illustrated in Figure 4. The serial arrangement of the cells 30 is terminated at opposite ends of the arrangement by plates 21 and 22, respectively. With the exception of those two plates, which are identical to the corresponding elements of the capacitor shown in Figure 3, the remainder of the capacitor units in the capacitor of Figure 4 are identical cells 30. Since plate 22 on which spacers 25 are disposed and plate 21 on which the anode 24 is formed have already been described, no repetition of the description of those elements is required.

Each cell 30 includes a bipolar metal plate or metal body 31. On one side of the metal body 31, a porous coating including a metal is formed in accordance with the preceding description. For example, a porous ruthenium oxide film containing tantalum oxide is present on one side of the plate 31. Electrically insulating spacing masses 32 are disposed in a pattern on that porous oxide coating. A porous tantalum anode 33, or an anode of a different material, is formed on the opposite side of the plate

31, completing the bipolar element of the cell 30. Generally, the anode 33 is formed first while a mask is present on the opposite side of the plate 31 to prevent the formation of excessive tantalum oxide.

5 After the anode is completed, the mask is removed and the oxide coating is formed on the side of the plate 31 opposite the anode. Thereafter, the spacer masses 32 are formed on the oxide coating. Finally, the sealant 34 is applied to one side of the plate

10 31, completing the cell 30. The order of the fabrication steps can be changed and the spacing masses can be formed on the anode rather than on the oxide coating provided appropriate changes are made in the cells at the ends of the serial arrangement.

15 The cells are then assembled by attaching the sealant to the plates of adjacent cells. The sealant may extend beyond individual cells and may merge into a single body along the whole length of the capacitor. The sealant may include laminated resin

20 layers that are heat sealed together beyond the edges of the plates 31. After the serial arrangement of the unit cells is assembled, the end units, i.e., the plate 21 with the attached anode 24 and the plate 22 with the attached spacer masses 25 on the

25 porous coating, are applied to opposite ends of the serial arrangement of identical unit cells to complete the mechanical assembly of the capacitor. Electrolyte is added to each of the cells through openings made in the sealant. The volume occupied

30 by the electrolyte may be evacuated before the electrolyte is introduced. After injection of the electrolyte, the sealant is again closed, finishing the electrolytic capacitor.

B When an ~~electrolytic~~ capacitor like the embodiment shown in Figure 4 includes a number of cells, it is not always possible to produce cells having identical characteristics. Particularly in capacitors according to the invention, where one electrode of each cell is significantly different in one or more of capacitance, resistance, and leakage current from the other electrode of that cell, excessive voltages may be applied to various cells. In order to avoid application of excessive voltages, a resistor, such as the resistors 35 illustrated in Figure 4, can be connected across the plates of each cell. If resistors are so employed, one such resistor should be connected across each pair of metal plates in the entire serial arrangement rather than the partial connection shown in Figure 4 which is shown only for illustrative purposes. The resistors should each have essentially the same resistance and provide a current path carrying substantially more current, for example, larger by a factor of ten, than the leakage current that flows through the capacitor. Although the resistors 35 are illustrated as discrete elements in Figure 4, distributed resistors between adjacent capacitor plates can be provided by employing a sealant with a desired, finite resistivity. Alternatively, an electrically conducting paint can be applied to the sealant in one or more stripes interconnecting the capacitor plates, i.e., electrodes, of the capacitor embodiments of Figures 3 and 4.

The invention has been described with respect to certain preferred embodiments. Various additions and modifications within the spirit of the invention will be apparent to those of skill in the relevant arts. Accordingly, the scope of the invention is

limited solely by the following claims.